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CHECK OF A THREE-DIMENSIONAL
REACTOR SHIELDING CODE
BY COMPARISON WITH
ML-1 REACTOR EXPERIMENT

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16. Abstract <p>The UNC-SAM-2 three-dimensional Monte Carlo reactor shielding code was used to compute the dose rates 500 feet from the center of the ML-1 reactor shield assembly. The ML-1 shield is a high-attenuation 4π unit shield composed of layers of metal and borated water. The agreement between the calculated and measured dose rates was excellent, indicating the validity of using the UNC-SAM-2 code for analyzing reactor shield assemblies of similar materials and geometries.</p>			
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CHECK OF A THREE-DIMENSIONAL REACTOR SHIELDING CODE

BY COMPARISON WITH ML-1 REACTOR EXPERIMENT

by Millard L. Wohl and Robert D. Schamberger*

SUMMARY

Shield analyses have been conducted for Lewis nuclear aircraft studies. The codes used in these analyses were UNC-SAM-2, SANE, and SAGE. UNC-SAM-2 is a three-dimensional code; SANE and SAGE are one-dimensional codes using the same data handling and computation routines. To check the codes, the dose rate 500 feet from the center of the ML-1 mobile reactor was calculated and compared with experimental dose measurements. The ML-1 reactor-shield system was chosen to check the code because the neutron shield material and geometry are similar to that of the airplane shield. It was also the only operational thermal, compact, unit-shielded, gas-cooled system for which careful shield measurements had been performed.

The neutron and gamma-ray dose rates at the control cab position of the operating ML-1 reactor were computed with UNC-SAM-2. These dose rates were compared with similar experimentally determined dose rates. The comparison of calculated and experimentally determined neutron and gamma-ray dose rates at ML-1 cab position (500 ft from reactor center) is shown below:

	Neutron dose rate, mrem/hr	Gamma-ray dose rate, mrem/hr
Calculated (UNC-SAM-2)	3.0±15 percent	2.8±10 percent
Experimental	3.3±35 percent	3.3±20 percent

The agreement between the calculated and experimental dose rates is excellent, indicating the validity of using the UNC-SAM-2 code for reactor shield assemblies of similar geometries and materials of known cross section. This calculation also conditionally verifies SANE and SAGE one-dimensional codes because they employ the same data handling and computation subroutines as UNC-SAM-2 except that UNC-SAM-2 handles three-dimensional geometric configurations.

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INTRODUCTION

Nuclear airplane shields are being analyzed at Lewis as part of a review of nuclear-airplane-related technology. The shields provide low dose rates throughout the aircraft. They must attenuate radiation by eight to nine orders of magnitude in all directions. In performing analyses involving such high radiation attenuation, many of the standard methods of shield analysis break down, due to the gross oversimplifications in the attenuation models and nuclear cross sections used. Many of these simple models ignore the secondary gamma-ray sources, which are often the most dominant source of radiation.

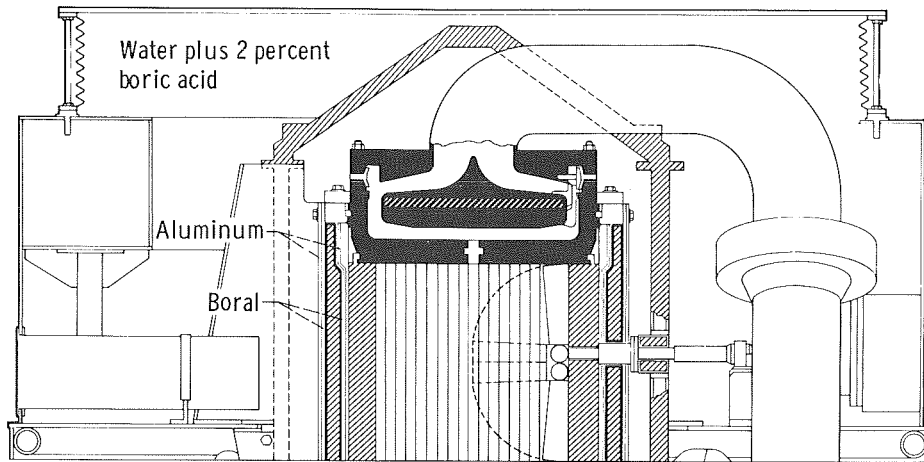
Only two relatively common methods (or hybrids thereof) provide accurate radiation dose rates in deep shield penetration analysis. These are the Monte Carlo and S_n methods. The Monte Carlo method is the more physically correct and is the only method presently capable of providing a true three-dimensional geometric reactor-shield mockup and analysis capability.

For this reason, Monte Carlo was selected to perform the detailed Lewis nuclear airplane shield analyses. The Monte Carlo codes used were SANE, SAGE, and UNC-SAM-2. Other than the detailed three-dimensional geometric region trajectory calculations, SANE and SAGE are essentially identical to UNC-SAM-2. They are one-dimensional neutron and gamma-ray codes, respectively, allowing homogenized radial core, reflector, and shield regions, and calculate energy-dependent fluxes. UNC-SAM-2, however, handles both neutrons and gamma rays in detailed three-dimensional geometric configurations.

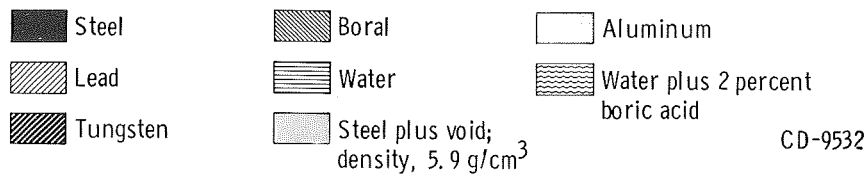
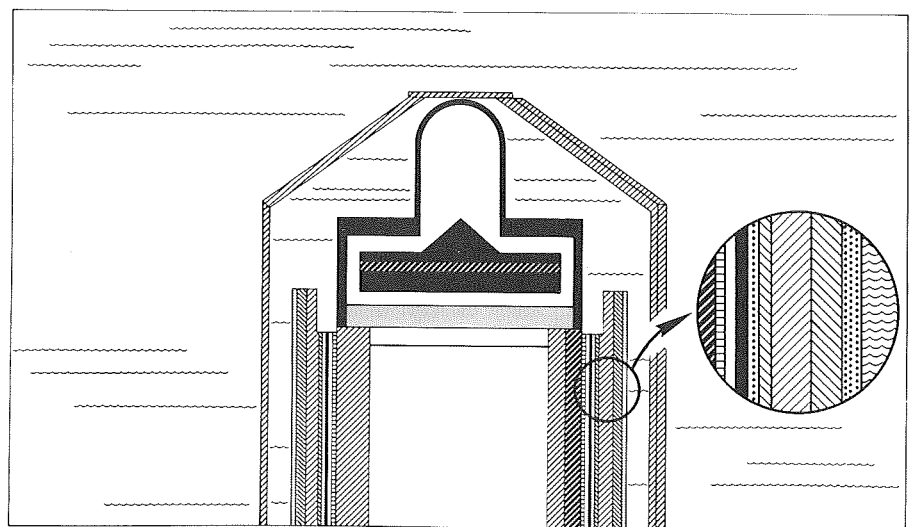
In order to check UNC-SAM-2, SANE, and SAGE, it was decided to check dose rate measurements performed for the ML-1 shielded reactor with the UNC-SAM-2 code. The check was made by calculating the dose rate at the control cab location (500 ft from the reactor) and comparing it with the measured dose rate. Verification of this code would also serve as a recommendation for use of the codes SANE and SAGE, which use similar data handling and computational methods. The ML-1 system (fig. 1) was chosen for the code check because the neutron shield material and geometry are similar to those for the airplane shield. It was also the only operational thermal, compact, unit-shielded, gas-cooled system for which careful shield measurements had been performed. This report presents the results of the check calculation.

ANALYTICAL METHODS

The UNC-SAM-2 code (ref. 3) simulates the transport of neutrons and gamma rays in variable three-dimensional geometries by Monte Carlo methods. It incorporates highly flexible importance sampling techniques which include dependence upon physical



(a) Cross section of actual ML-1 reactor-shield assembly.



(b) Computer representation of ML-1 reactor-shield assembly.

Figure 1. - Configurations for comparison of UNC-SAM-2 computer program with ML-1 shield measurements.

region, particle energy, and particle direction. Suitable specification of region, energy, and direction importance functions places the emphasis upon those particles most likely to contribute to the dose at the desired location. The cross section handling, geometric tracking, and importance sampling routines (ref. 4) were independently checked for a simple representative example. Special routines were designed solely to perform these checks.

The ML-1 reactor-shield geometry is shown in figure 1 along with the configuration seen by the CDC-1604-A computer via UNC-SAM-2. The metal-water shield is performance-dominated by hydrogen attenuation. The ducting is represented in a crude fashion but is adequate for the 500-foot dose rate computed.

Neutron fluxes were computed at the 500-foot distant detector point. For the ML-1 shield, about six orders of magnitude of attenuation are required.

RESULTS AND DISCUSSION

The calculated neutron dose rate for the ML-1 reactor at a power of 2.2 megawatts was 3.0 millirem per hour. The internal calculational accuracy of this result is estimated within the code to be ± 15 percent. For the ML-1 shield, where the neutron attenuation is dominated by water, uncertainties in the neutron cross sections are small or unimportant.

In the gamma-ray problem, fluxes at the control cab were calculated in six energy intervals from 0.1 to 10 MeV. These were converted to dose rate and the resulting gamma-ray dose rate at 500 feet was 2.8 millirem per hour with an internal statistical accuracy of about ± 10 percent. The major component of the gamma-ray dose rate is due to neutron captures in the water shield, since gamma-ray production due to resonance capture and inelastic neutron scattering in the metal is less than 2 percent of the total gamma-ray source, including core gammas.

The results of experimental measurements of the ML-1 neutron and gamma-ray dose rates under operational conditions have been reported in a presentation by Whittum and Witthaus of Aerojet General Nucleonics, Inc. Reported values of the neutron and gamma-ray dose ratio at 500 feet were each equal to 3.3 millirem per hour which is in good agreement with the dose rates calculated with UNC-SAM-2. The comparison of calculated (UNC-SAM-2) and experimentally determined neutron and gamma-ray dose rates at ML-1 cab position (500 ft from reactor center) is summarized in the following table:

	Neutron dose rate, mrem/hr	Gamma-ray dose rate, mrem/hr
Calculated (UNC-SAM-2)	3.0±15 percent	2.8±10 percent
Experimental	3.3±35 percent	3.3±20 percent

CONCLUDING REMARKS

While it cannot be inferred from the check calculation described herein that Monte Carlo codes such as UNC-SAM-2 are infallible tools in providing highly accurate dose rates at deep penetrations (attenuations of 10^8 and greater), the comparison does lend some credence to results determined from careful, accurate use of UNC-SAM-2 for shield assemblies with geometries similar to the ML-1 and known cross sections.

The ML-1 shield had nearly rotational symmetry, and the calculation could have been performed with a two-dimensional discrete ordinates code (supplied with appropriate cross sections and transfer matrices). The computer time for this type of analysis is comparable to that required in a Monte Carlo calculation. When a true three-dimensional geometry is required, however, the Monte Carlo approach is the only accurate method available. Three-dimensional discrete ordinates codes are not on the horizon in the near future, and no present method other than Monte Carlo allows the accurate three-dimensional spatial determination of secondary gamma-ray sources, which is probably the key factor in meaningful shield analysis.

The verification of the UNC-SAM-2 code in the ML-1 study is considered to also substantially verify the SANE and SAGE codes used in all the parametric spherical shield analyses in the Lewis nuclear airplane studies. SANE and SAGE use the same cross-section handling procedures and tracking techniques and many of the same importance sampling features as UNC-SAM-2.

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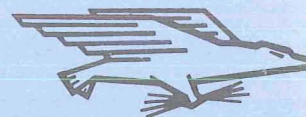
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